THE ASTROPHYSICAL JOURNAL, ???:L??–L??, 2006 ??? ??, ASTRO-PH/0606389
Preprint typeset using LaTeX style emulateapj v. 12/14/05



# THE HARD X-RAY SPECTRAL SLOPE AS AN ACCRETION-RATE INDICATOR IN RADIO-QUIET ACTIVE GALACTIC NUCLEI

OHAD SHEMMER,[1] W. N. BRANDT,[1] HAGAI NETZER,[2] ROBERTO MAIOLINO,[3] AND SHAI KASPI[2,4]

*Received 2006 May 11; accepted 2006 June 14*

## ABSTRACT

We present new *XMM-Newton* observations of two luminous and high accretion-rate radio-quiet active galactic nuclei (AGNs) at $z \sim 2$. Together with archival X-ray and rest-frame optical spectra of three sources with similar properties as well as 25 moderate-luminosity radio-quiet AGNs at $z < 0.5$, we investigate, for the first time, the dependence of the hard ($\gtrsim 2$ keV) X-ray power-law photon index on the broad H$\beta$ emission-line width and on the accretion rate across $\sim 3$ orders of magnitude in AGN luminosity. Provided the accretion rates of the five luminous sources can be estimated by extrapolating the well-known broad-line region size-luminosity relation to high luminosities, we find that the photon indices of these sources, while consistent with those expected from their accretion rates, are significantly higher than expected from the widths of their H$\beta$ lines. We argue that, within the limits of our sample, the hard-X-ray photon index depends primarily on the accretion rate.

*Subject headings:* galaxies: active – galaxies: nuclei – X-rays: galaxies – quasars: emission lines – quasars: individual (Q 1346−036, HE 2217−2818)

## 1. WHAT DETERMINES THE X-RAY POWER-LAW SPECTRUM OF ACTIVE GALACTIC NUCLEI?

It is widely accepted that the hard ($\gtrsim 2$ keV) X-ray emission from active galactic nuclei (AGNs) is primarily produced via unsaturated inverse Compton scattering of UV–soft-X-ray photons from the accretion disk by a corona of hot, likely thermal, electrons (e.g., Haardt & Maraschi 1991; Zdziarski, Poutanen, & Johnson 2000; Kawaguchi, Shimura, & Mineshige 2001). The emitted X-ray photon spectrum in the $\approx$2–100 keV energy range is best described by a power-law of the form $N_E \propto E^{-\Gamma}$, where $\Gamma$, the photon index, takes a fairly constant value of $\sim$2, and is predicted to be only weakly sensitive to large changes in the electron temperature and the optical depth in the corona (e.g., Haardt & Maraschi 1991). Throughout this work, we refer to $\Gamma$ only as the photon index in the hard ($\gtrsim 2$ keV) X-ray band.

Nandra & Pounds (1994) found a $\langle\Gamma\rangle$=1.95$\pm$0.15 for a sample of bright Seyfert 1 galaxies, confirming the mean predicted $\Gamma$ and its small dispersion. Brandt, Mathur, & Elvis (1997) have studied the X-ray spectra of a sample of nearby AGNs, including low–moderate luminosity Narrow-Line Seyfert 1 (NLS1) galaxies, defined as type 1 AGNs having H$\beta$ full width at half-maximum intensity (FWHM) $\lesssim 2000$ km s$^{-1}$ (Osterbrock & Pogge 1985). The addition of NLS1s, which were previously overlooked due to observational biases, broadened the range of $\Gamma$ values, and allowed Brandt et al. (1997) to find that $\Gamma$ is anticorrelated with FWHM(H$\beta$). This extended the analogous relation between FWHM(H$\beta$) and the effective X-ray spectral slope in the 0.1–2.0 keV band to harder X-rays (e.g., Boller, Brandt, & Fink 1996; Laor et al. 1997). The pseudo-thermal soft-X-ray excess radiation may be responsible for cooling the corona, thus steepening the X-ray spectrum (e.g., Pounds, Done, & Osborne 1995), and the pronounced soft excesses of NLS1s (e.g., Puchnarewicz et al. 1995) may readily explain their steep X-ray spectra and the $\Gamma$-FWHM(H$\beta$) anticorrelation.

The remarkable dependence of the spectral shape of the X-ray emission, originating $\lesssim 30\,R_S$ from the central engine, on the width of a broad-emission line region (BELR) line, emitted at $\approx 10^4\,R_S$, was interpreted as a fundamental dependence of $\Gamma$ on the accretion rate, since, as explained below, FWHM(H$\beta$) is considered an accretion-rate indicator in type 1 AGNs (e.g., Boroson & Green 1992; Brandt & Boller 1998). A high accretion rate would increase the disk temperature hence producing more soft-X-ray radiation (the "soft excess") and, at the same time, increase the Compton cooling of the corona and steepen the hard-X-ray power law.

Recent X-ray studies of nearby ($z \lesssim 0.5$) type 1 radio-quiet quasars (RQQs) have consistently shown that $\Gamma \sim 2.0 \pm 0.5$, and some of those studies confirmed the Brandt et al. (1997) $\Gamma$-FWHM(H$\beta$) relationship (e.g., Leighly 1999; Reeves & Turner 2000; Porquet et al. 2004; Piconcelli et al. 2005, hereafter P05; Brocksopp et al. 2006). Photon indices of $\Gamma \sim 2.0$ are also observed for $0.5 \lesssim z \lesssim 6$ RQQs (e.g., Reeves & Turner 2000; Page et al. 2005; Shemmer et al. 2005), however, the spread in their $\Gamma$ values seems smaller than that for nearby sources (see Fig. 3 of Shemmer et al. 2005). On the other hand, Grupe et al. (2006) report $\langle\Gamma\rangle = 2.21 \pm 0.52$ for a sample of $z > 4$ RQQs, and suggest that the relatively steep X-ray spectra of such sources may be attributed to high accretion rates, in analogy with NLS1s.

In this *Letter* we test the hypothesis that the accretion rate largely determines the hard-X-ray spectral slope in AGNs, and argue that previous studies have not been able to break the degeneracy between the dependence of $\Gamma$ on FWHM(H$\beta$) and the accretion rate, since highly luminous AGNs were left out of the analyses (e.g., Porquet et al. 2004). This is performed by investigating X-ray and H$\beta$ spectral-region data for a well-defined sample of 30 moderate–high-luminosity RQQs, selected for having high-quality X-ray and H$\beta$-region spectroscopy. Five of the sources are luminous RQQs at $z \sim 2$, allowing, for the first time in this context, expansion of the AGN parameter space by $\sim 3$ orders of magnitude in luminosity and

[1] Department of Astronomy & Astrophysics, Pennsylvania State University, University Park, PA 16802, USA; ohad@astro.psu.edu.
[2] School of Physics & Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv 69978, Israel.
[3] INAF - Osservatorio Astrofisico di Arcetri, L.go E. Fermi 5, 50125 Firenze, Italy.
[4] Physics Department, Technion, Haifa 32000, Israel.

TABLE 1
*XMM-Newton* OBSERVATION LOG

| QUASAR | RA (J2000.0) | DEC (J2000.0) | $z^{a}$ | $N_{\rm H}{}^{b}$ | OBSERVATION START DATE | NET EXPOSURE TIME (KS) / SOURCE COUNTS MOS1 | MOS2 | PN |
|---|---|---|---|---|---|---|---|---|
| Q 1346−036 | 13 48 44.08 | −03 53 25.0 | 2.370 | 2.47 | 2005 Jul 05 | 10.4 / 90 | 10.4 / 144 | 9.4 / 520 |
| HE 2217−2818 | 22 20 06.77 | −28 03 23.9 | 2.414 | 1.28 | 2005 Oct 31 | 25.1 / 732 | 25.1 / 790 | 21.2 / 2968 |

[a]Systemic redshift measured from the optical emission lines and obtained from S04.
[b]Neutral Galactic absorption column density in units of $10^{20}$ cm$^{-2}$ obtained from Dickey & Lockman (1990).

black-hole mass ($M_{\rm BH}$). Two of the $z\sim2$ RQQs, Q 1346−036 and HE 2217−2818, were selected for *XMM-Newton* observations from the Shemmer et al. (2004; hereafter S04) sample of luminous and high accretion-rate quasars based on their expected high X-ray fluxes in that sample. In § 2 we present the new *XMM-Newton* observations, their reduction, and the X-ray spectral fitting of these two sources; their X-ray and optical properties are presented in § 3. In § 4 we discuss our results, and in particular, the dependence of $\Gamma$ on the accretion rate for AGNs. Throughout this work we consider only radio-quiet AGNs to avoid any contribution from jet-related emission to the X-ray spectra. Luminosity distances are computed using the standard cosmological model with parameters $\Omega_\Lambda=0.7$, $\Omega_M=0.3$, and $H_0=70$ km s$^{-1}$ Mpc$^{-1}$.

## 2. XMM-*NEWTON* OBSERVATIONS AND DATA REDUCTION

Table 1 gives a log of the *XMM-Newton* (Jansen et al. 2001) imaging spectroscopic observations for Q 1346−036 and HE 2217−2818; the data were processed using standard *XMM-Newton* Science Analysis System[5] v6.5.0 tasks. The event files of the observation of Q 1346−036 were filtered to remove ∼35 ks of flaring-activity periods; the net exposure times in Table 1 reflect the filtered data (time filtering was not required for the HE 2217−2818 observation). The X-ray spectra of the quasars were extracted from the images of all three European Photon Imaging Camera (EPIC) detectors using apertures with radii of 30″. Background regions were at least as large as the source regions. The spectra of Q 1346−036 (HE 2217−2818) were grouped with a minimum of 10 (50) counts per bin. Joint spectral fitting of the data from all three EPIC detectors for each quasar was performed with XSPEC v11.3.2 (Arnaud 1996). We employed Galactic-absorbed power-law models at observed-frame energies >0.6 keV, corresponding to >2 keV in the rest-frame of each quasar, where the underlying power-law hard-X-ray spectrum is less prone to contamination due to any potential soft excess emission and ionized absorption. The best-fit $\Gamma$ values and power-law normalizations from these fits are given in Table 2, and the data, their joint, best-fit spectra, and residuals appear in Fig. 1.

We searched for intrinsic absorption in each quasar by jointly fitting the spectra with a Galactic-absorbed power law model including an intrinsic (redshifted) neutral-absorption component with solar abundances in the same energy range as before. None of the quasars shows significant intrinsic absorption; upper limits on intrinsic $N_{\rm H}$ values appear in Table 2. Fig. 1 includes a $\Gamma$-$N_{\rm H}$ confidence-contour plot from this fitting for each quasar. By applying $F$-tests between the models including intrinsic absorption and those that exclude it, we found that neither data set requires an intrinsic absorption component. We also note that our *XMM-Newton* spectra show no indication of Compton-reflection components or Fe K$\alpha$ lines; such features are expected to be relatively weak, below our detection threshold, in the luminous sources under study in this work (e.g., the Fe K$\alpha$ equivalent width is expected to be $\lesssim 50$ eV; Page et al. 2004a).

Finally, we searched for rapid (∼1 hr timescale in the rest frame) X-ray variations in the *XMM-Newton* data of the two quasars by applying Kolmogorov-Smirnov (KS) tests to the lists of photon arrival times from the event files, but no significant variations were detected.

[5] http://xmm.esac.esa.int/sas.

## 3. X-RAY AND OPTICAL PROPERTIES

Basic X-ray and optical properties of Q 1346−036 and HE 2217−2818 are given in Table 2. The luminosity at a rest-frame wavelength of 5100 Å is given in column (6), and FWHM(H$\beta$) is given in column (7); these data were obtained from S04. Column (8) gives $M_{\rm BH}$, determined as

$$\frac{M_{\rm BH}}{10^6 M_\odot} = 4.35 \left[\frac{\nu L_\nu(5100\,\text{Å})}{10^{44}\,\rm ergs\,s^{-1}}\right]^{0.7} \left[\frac{\rm FWHM(H\beta)}{10^3\,\rm km\,s^{-1}}\right]^2, \quad (1)$$

and based on the recent reverberation-mapping results of Peterson et al. (2004) and the Kaspi et al. (2005) BELR size-luminosity relation (see also Kaspi et al. 2000). We note that this relation relies on a sample of AGNs having luminosities up to $\approx 10^{46}$ ergs s$^{-1}$, and extrapolating it to higher luminosities is somewhat uncertain; a reverberation-mapping effort is underway to test the validity of such extrapolations (S. Kaspi et al., in preparation). However, as $M_{\rm BH}$ is expected to scale with luminosity, for a given H$\beta$ width, and since in this work we perform only nonparametric statistical ranking tests, our results are not significantly sensitive to the precise coefficient values in this relation. Using equation (1), the accretion-rate ratios (col. [9]), $L_{\rm bol}/L_{\rm Edd}$ (where $L_{\rm bol}$ is the bolometric luminosity; hereafter $L/L_{\rm Edd}$), are given by

$$L/L_{\rm Edd} = 0.15 f(L) \left[\frac{\nu L_\nu(5100\,\text{Å})}{10^{44}\,\rm ergs\,s^{-1}}\right]^{0.3} \left[\frac{\rm FWHM(H\beta)}{10^3\,\rm km\,s^{-1}}\right]^{-2}, \quad (2)$$

where we have employed equation (21) of Marconi et al. (2004) to obtain $f(L)$, which is the luminosity-dependent bolometric correction to $\nu L_\nu(5100\,\text{Å})$. The bolometric correction is $f\sim6-8$ ($f\simeq5$) for the $z<0.5$ ($z\sim2$) sources in this work.

The optical–X-ray spectral slopes in column (10) are defined as $\alpha_{\rm ox} = \log(f_{2\,\rm keV}/f_{2500\,\text{Å}})/\log(\nu_{2\,\rm keV}/\nu_{2500\,\text{Å}})$, where $f_{2\,\rm keV}$ and $f_{2500\,\text{Å}}$ are the flux densities at 2 keV and 2500 Å, respectively. The $\alpha_{\rm ox}$ values were derived using the photon indices and fluxes in columns (2) and (3), respectively, and the optical luminosities in column (6), assuming a UV continuum of the form $f_\nu \propto \nu^{-0.5}$ (Vanden Berk et al. 2001). The $\alpha_{\rm ox}$ values for our sources are consistent with the expected values, given their optical luminosities (e.g., Steffen et al. 2006).

TABLE 2
BEST-FIT X-RAY SPECTRAL PARAMETERS AND OPTICAL PROPERTIES

| QUASAR (1) | $\Gamma$ (2) | $f_\nu(1\,\mathrm{keV})$[a] (3) | $\chi^2$ (d.o.f) (4) | $N_{\rm H}$[b] (5) | $\log \nu L_\nu(5100\,\text{Å})$ (ergs s$^{-1}$) (6) | FWHM(H$\beta$) (km s$^{-1}$) (7) | $\log M_{\rm BH}$ ($M_\odot$) (8) | $L/L_{\rm Edd}$ (9) | $\alpha_{\rm ox}$ (10) |
|---|---|---|---|---|---|---|---|---|---|
| Q 1346−036 | $2.02\pm0.17$ | $1.6\pm0.2$ | 37 (52) | $\leq 1.2$ | 46.9 | 5100 | 10.0 | 0.3 | −1.69 |
| HE 2217−2818 | $1.97\pm0.06$ | $3.5\pm0.2$ | 50 (50) | $\leq 0.6$ | 47.2 | 5200 | 10.3 | 0.3 | −1.69 |

NOTE. — The best-fit photon index, normalization, and $\chi^2$ were obtained from a Galactic-absorbed power-law model. Errors represent 90% confidence limits, taking one parameter of interest ($\Delta\chi^2 = 2.71$).

[a]Power-law normalization for the pn data, taken from joint fitting of all three EPIC detectors with the Galactic-absorbed power-law model, and is given as the flux density at an observed-frame energy of 1 keV with units of $10^{-31}$ ergs cm$^{-2}$ s$^{-1}$ Hz$^{-1}$.

[b]Intrinsic column density in units of $10^{22}$ cm$^{-2}$. Upper limits were computed with the intrinsically-absorbed power-law model with Galactic absorption, and represent 90% confidence limits for each value.

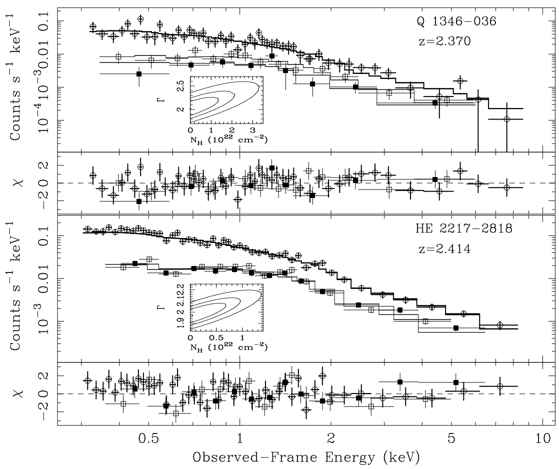


FIG. 1.— Data, best-fit spectra, and residuals for the *XMM-Newton* observations of Q 1346−036 (*top*) and HE 2217−2818 (*bottom*). Open circles, filled squares, and open squares represent the EPIC pn, MOS1, and MOS2 data, respectively. Solid lines represent the best-fit model for each spectrum, and the thick line marks the best-fit model for the pn data. The data were fitted with a Galactic-absorbed power-law model in the observed-frame >0.6 keV band, that was extrapolated to 0.3 keV in the observed frame. The $\chi$ residuals are in units of $\sigma$ with error bars of size 1. The inset in each panel shows 68%, 90%, and 99% confidence contours for $\Gamma$ and $N_{\rm H}$, when the data are fitted with an additional neutral intrinsic-absorption component.

## 4. IS Γ AN ACCRETION-RATE INDICATOR?

In Fig. 2 we plot $\Gamma$ vs. $\nu L_\nu(5100\,\text{Å})$, FWHM(H$\beta$), $M_{\rm BH}$, and $L/L_{\rm Edd}$ for Q 1346−036 and HE 2217−2818. Fig. 2 also includes 28 unabsorbed Palomar Green (PG) RQQs (Schmidt & Green 1983) which have high-quality *XMM-Newton* and optical data; 25 of the quasars are at $z < 0.5$ and three, PG 1247+267, PG 1630+377, and PG 1634+706, are at $z \sim 1.5-2$. Photon indices in the 2–12 keV rest-frame band for 27 of the PG quasars were obtained from Table 3 of P05; the photon index of PG 1247+267 was obtained from Page et al. (2004b). Optical data for the PG quasars were obtained from Neugebauer et al. (1987), Boroson & Green (1992), Nishihara et al. (1997), and McIntosh et al. (1999), and processed with equations (1) and (2). The fact that the X-ray and optical data are not contemporaneous may provide a source for scatter in Fig. 2. However, since most of the PG quasars do not exhibit significant variations in $\Gamma$ (e.g., George et al. 2000) and H$\beta$ width (Kaspi et al. 2000), and their optical-continuum flux variations are typically at a level of $\lesssim 50\%$ over timescales of several years (Kaspi et al. 2000), the data in Fig. 2 are not expected to be strongly affected by variability (see also equations [1] and [2]).

We computed Spearman rank-correlation coefficients between $\Gamma$ and $\nu L_\nu(5100\,\text{Å})$, FWHM(H$\beta$), $M_{\rm BH}$, and $L/L_{\rm Edd}$ for the 25 low-luminosity, $z < 0.5$ sources. We found that, with the exception of $\nu L_\nu(5100\,\text{Å})$, the investigated properties are significantly correlated with $\Gamma$ (with 99.9% confidence), in agreement with Porquet et al. (2004) and P05. The $\Gamma$-$M_{\rm BH}$ and $\Gamma$-$L/L_{\rm Edd}$ correlations are largely a consequence of the $\Gamma$-FWHM(H$\beta$) correlation (Brandt et al. 1997), since both $M_{\rm BH}$ and $L/L_{\rm Edd}$ depend strongly on FWHM(H$\beta$), and the sample spans a relatively narrow luminosity range [$\nu L_\nu(5100\,\text{Å}) \sim 10^{44}$–$10^{46}$ ergs s$^{-1}$; see eqs. (1) and (2), and Fig. 2*a*]. The absence of a $\Gamma$-$L$ correlation has been observed for larger AGN samples spanning broader luminosity ranges (e.g., Shemmer et al. 2005; Vignali et al. 2005).

We repeated the above correlations, adding the five luminous quasars at $z \sim 2$ to the analysis. We found that $\Gamma$ remains uncorrelated with $\nu L_\nu(5100\,\text{Å})$, and that the $\Gamma$-$M_{\rm BH}$ correlation disappeared. This is a consequence of extending the luminosity and $M_{\rm BH}$ ranges by $\sim 3$ orders of magnitude, while our measured $\Gamma$ values are typical of high-redshift quasars (e.g., Shemmer et al. 2005). The $\Gamma$-FWHM(H$\beta$) correlation remained significant with 99.9% confidence, but the (anti-)correlation coefficient dropped from 0.61 to 0.44. The $\Gamma$-$L/L_{\rm Edd}$ correlation remained significant, with 99.9% confidence, and the correlation coefficient, 0.60, has not changed. This supports the hypothesis that the X-ray photon index depends primarily on $L/L_{\rm Edd}$.

To test the hypothesis that $\Gamma$ depends primarily on $L/L_{\rm Edd}$, we considered AGNs from Fig. 2*b* with 3500<FWHM(H$\beta$)<6000 km s$^{-1}$ [which is the FWHM(H$\beta$) interval of the five luminous $z \sim 2$ sources as well as that of the majority of the S04 quasars], and checked the significance of the deviation between the $\Gamma$ values of the five luminous sources and the $\Gamma$ values of the eight $z < 0.5$ PG quasars in that FWHM(H$\beta$) interval. A Mann-Whitney (MW) nonparametric rank test shows that the $\Gamma$ distributions of the five high-luminosity quasars and the eight moderate-luminosity quasars are significantly different with 99.9% confidence. We also performed a KS test on the two $\Gamma$ distributions and found that the $\Gamma$ values of the two groups of quasars cannot be drawn from a single distribution with 99% confidence. On the other hand, MW and KS tests showed that, in the $0.2 \lesssim L/L_{\rm Edd} \lesssim 0.5$ range (representing the range of $L/L_{\rm Edd}$ values of the five luminous quasars as well as that of the majority of the S04 sources), the $\Gamma$ values of the two groups of quasars are not significantly different (as can be clearly seen from Fig. 2*d*).

Compton-reflection contributions to the X-ray spectra of all 30 quasars are expected to be negligible given their moderate–high luminosities (e.g., Page et al. 2004a, but see also Jiménez-Bailón et al. 2005). However, Page et

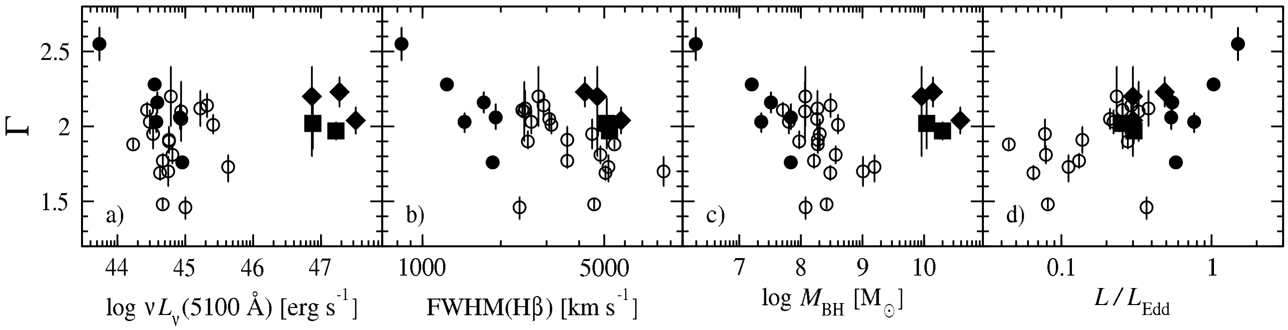


FIG. 2.— The hard-X-ray photon index vs. (*a*) $\nu L_\nu$(5100 Å), (*b*) FWHM(H$\beta$), (*c*) $M_{\rm BH}$, and (*d*) $L/L_{\rm Edd}$. Open circles mark PG quasars at $z < 0.5$ from the P05 sample; the NLS1s in that sample are marked with filled circles. Diamonds mark luminous PG quasars at $z \sim 1.5-2$ with archival *XMM-Newton* data. Q 1346−036 and HE 2217−2818 are marked with squares.

al. (2004b) detected Compton reflection in PG 1247+267. We reanalyzed the X-ray spectrum of this source, and found that the hard-X-ray excess has no significant effect on Γ, whether fitted with or without a Compton-reflection component (consistent with Page et al. 2004b). We also searched for systematic differences between the analyses of Q 1346−036 and HE 2217−2818 and the P05 sources by reanalyzing the *XMM-Newton* spectra of PG 1630+377, PG 1634+706, and the eight $z < 0.5$ PG quasars with 3500<FWHM(H$\beta$)<6000 km s$^{-1}$. We reproduced the P05 photon indices in the rest-frame 2–12 keV band with no systematic deviations from their values. Additionally, fitting the data of Q 1346−036 and HE 2217−2818 from rest-frame 2–12 keV (observed-frame 0.6–3.5 keV) did not alter our results significantly. We note that for five $z < 0.5$ PG quasars with 3500<FWHM(H$\beta$)<6000 km s$^{-1}$ the Γ values from P05 are consistent with those from Porquet et al. (2004), and are somewhat lower than those from Brocksopp et al. (2006), due perhaps to analyses differences.

Our results suggest that Γ depends primarily on $L/L_{\rm Edd}$, as pointed out by e.g., Brandt & Boller (1998) and Laor (2000). The key difference between this work and previous studies (e.g., Porquet et al. 2004; Wang, Watarai, & Mineshige 2004; Bian 2005) is that we expanded the quasar parameter space by adding highly luminous sources to the correlations (see Fig. 2*a*). Such luminous quasars are found only at $z \sim$1–4, and their H$\beta$ lines, required for $M_{\rm BH}$ and $L/L_{\rm Edd}$ determinations (see e.g., S04; Baskin & Laor 2005), are shifted into the observed near-infrared band. X-ray and H$\beta$ spectral-region data of additional high-luminosity quasars are crucial to break the degeneracy between the Γ-FWHM(H$\beta$) and Γ-$L/L_{\rm Edd}$ correlations and conclude that the X-ray power-law photon index depends on the accretion rate. Ultimately, a large enough inventory of X-ray and H$\beta$ spectral-region data for luminous, high-redshift quasars will allow testing of the hypothesis that such sources are analogous to NLS1s (e.g., Grupe et al. 2006).

This work is based on observations obtained with *XMM-Newton*, an ESA science mission with instruments and contributions directly funded by ESA Member States and the USA (NASA). We thank an anonymous referee for constructive comments, and George Chartas and Aaron Steffen for fruitful discussions. We gratefully acknowledge the financial support of NASA grant NNG05GP00G (O. S, W. N. B), NASA LTSA grant NAG5-13035 (O. S, W. N. B), and the Zeff Fellowship at the Technion (S. K.). This work is supported by the Israel Science Foundation grant 232/03.

REFERENCES


Arnaud, K. A. 1996, ASP Conf. Ser. 101: Astronomical Data Analysis Software and Systems V, 101, 17
Baskin, A., & Laor, A. 2005, MNRAS, 356, 1029
Bian, W.-H. 2005, Chinese Journal of Astronony and Astrophysics, 5, 289
Boller, T., Brandt, W. N., & Fink, H. 1996, A&A, 305, 53
Boroson, T. A., & Green, R. F. 1992, ApJS, 80, 109
Brandt, W. N., Mathur, S., & Elvis, M. 1997, MNRAS, 285, L25
Brandt, N., & Boller, T. 1998, Astronomische Nachrichten, 319, 163
Brocksopp, C., et al. 2006, MNRAS, 366, 953
Dickey, J. M., & Lockman, F. J. 1990, ARA&A, 28, 215
George, I. M., et al. 2000, ApJ, 531, 52
Grupe, D., Mathur, S., Wilkes, B., & Osmer, P. 2006, AJ, 131, 55
Haardt, F., & Maraschi, L. 1991, ApJ, 380, L51
Jansen, F., et al. 2001, A&A, 365, L1
Jiménez-Bailón, E., Piconcelli, E., Guainazzi, M., Schartel, N., Rodríguez-Pascual, P. M., & Santos-Lleó, M. 2005, A&A, 435, 449
Kaspi, S., Smith, P. S., Netzer, H., Maoz, D., Jannuzi, B. T., & Giveon, U. 2000, ApJ, 533, 631
Kaspi, S., Maoz, D., Netzer, H., Peterson, B. M., Vestergaard, M., & Jannuzi, B. T. 2005, ApJ, 629, 61
Kawaguchi, T., Shimura, T., & Mineshige, S. 2001, ApJ, 546, 966
Laor, A., et al. 1997, ApJ, 477, 93
Laor, A. 2000, New Astronomy Review, 44, 503
Leighly, K. M. 1999, ApJS, 125, 317
Marconi, A., Risaliti, G., Gilli, R., Hunt, L. K., Maiolino, R., & Salvati, M. 2004, MNRAS, 351, 169
McIntosh, D. H., Rieke, M. J., Rix, H.-W., Foltz, C. B., & Weymann, R. J. 1999, ApJ, 514, 40
Nandra, K., & Pounds, K. A. 1994, MNRAS, 268, 405
Neugebauer, G., Green, R. F., Matthews, K., Schmidt, M., Soifer, B. T., & Bennett, J. 1987, ApJS, 63, 615
Nishihara, E., et al. 1997, ApJ, 488, L27
Osterbrock, D. E., & Pogge, R. W. 1985, ApJ, 297, 166
Page, K. L., O'Brien, P. T., Reeves, J. N., & Turner, M. J. L. 2004a, MNRAS, 347, 316
Page, K. L., Reeves, J. N., O'Brien, P. T., Turner, M. J. L., & Worrall, D. M. 2004b, MNRAS, 353, 133
Page, K. L., Reeves, J. N., O'Brien, P. T., & Turner, M. J. L. 2005, MNRAS, 364, 195
Peterson, B. M., et al. 2004, ApJ, 613, 682
Piconcelli, E., et al. 2005, A&A, 432, 15 (P05)
Porquet, D., Reeves, J. N., O'Brien, P., & Brinkmann, W. 2004, A&A, 422, 85
Pounds, K. A., Done, C., & Osborne, J. P. 1995, MNRAS, 277, L5
Puchnarewicz, E. M., Mason, K. O., Siemiginowska, A., & Pounds, K. A. 1995, MNRAS, 276, 20
Reeves, J. N. & Turner, M. J. L. 2000, MNRAS, 316, 234
Schmidt, M., & Green, R. F. 1983, ApJ, 269, 352
Shemmer, O., Netzer, H., Maiolino, R., Oliva, E., Croom, S., Corbett, E., & di Fabrizio, L. 2004, ApJ, 614, 547 (S04)
Shemmer, O., Brandt, W. N., Vignali, C., Schneider, D. P., Fan, X., Richards, G. T., & Strauss, M. A. 2005, ApJ, 630, 729
Steffen, A. T., et al. 2006, AJ, 131, 2826
Vanden Berk, D. E., et al. 2001, AJ, 122, 549
Vignali, C., Brandt, W. N., Schneider, D. P., & Kaspi, S. 2005, AJ, 129, 2519
Wang, J.-M., Watarai, K.-Y., & Mineshige, S. 2004, ApJ, 607, L107
Zdziarski, A. A., Poutanen, J., & Johnson, W. N. 2000, ApJ, 542, 703